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THE LEGIBILITY OF TYPE AS A FUNCTION OF REFLECTANCE OF BACKGROUND UNDER LOW ILLUMINATION

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JUNE 1952

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FOREWORD

This report was prepared by the Institute for Applied Experimental Psychology, Tufts College, under USAF Contract No. W33-038 ac-14559, Supplemental Agreement No. S7. The contract is administered by the Psychology Branch, Aero Medical Laboratory, Research Division, Wright Air Development Center, under Research and Development Order No. 694-15, Numerical, Graphic, and Verbal Information, with Major Edward L. Cole acting as project engineer.

WADC TECHNICAL REPORT 52-85

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June 1952

Contract No. W33-038 ac-14559
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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT

The legibility of lower case type as a function of illumination level, reflectance of background, and type size was measured by means of speed and accuracy scores on a letter cross-out test. Simulated red cockpit illumination was used, covering the range from 0.014 to 0.129 foot-candles. Red light reflectance of background was varied from 0.26 to 0.87. Type sizes were 6- and 8-point. Scores fell off at an accelerated rate with decreasing illumination and background reflectance, and were lower under all conditions for 6- than for 8-point type. The specific application of these data to chart design will be covered in a subsequent report.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

Robert H. Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
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THE LEGIBILITY OF TYPE AS A FUNCTION OF REFLECTANCE OF BACKGROUND UNDER LOW ILLUMINATION

SECTION I

INTRODUCTION

The study here reported is one of a series concerned with the design of aeronautical charts for use under red light. The low reflectance of certain areas on colored charts materially reduces the contrast between overprinting and background. The resulting loss in legibility might be of minor consequence in daylight, but under the low intensity of red cockpit illumination the problem becomes more serious.

To consider an example, the elevation tints currently in use constitute a graded series of 11 steps. If this series is to be effective under red light, the steps must be differentiated in terms of brightness or relative reflectance. Of the 11 elevation tints, the darkest has a red light reflectance of about 0.35. Overprinting is often difficult to read against such a background.

A possible adjustment would be to lighten the whole scale, making the minimum reflectance, for example, 0.50. One consequence of this would be to reduce the size of the steps and make adjacent elevation levels less readily discriminable. Even with 11 steps distributed uniformly over the range from maximum reflectance to 0.35, the confusion of material on a chart, low illumination level, and other conditions of the visual field make it difficult to distinguish adjacent steps at a glance. Therefore some compromise is necessary between the conflicting demands of legibility of overprinting and discrimination of elevation levels. Various factors are to be considered in arriving at this compromise, among them, the amount of legibility loss under the conditions of background and illumination level in question. The study here reported was done to provide data on this phase of the problem.

It is necessary to consider the possible effects of characteristics of the type used. Such variables as type face, point size, and width of stroke have been studied by previous investigators under conditions of ordinary reading of book text, and also to some extent by techniques requiring the identification of individual letters. Under conditions of ordinary reading, these factors, when varied within moderate limits, have been found to affect legibility to a measurable, but rather minor, extent. When tested by such criteria as, for example, the distance at which individual letters can be identified, such factors, particularly the measurable ones of height, width, and stroke-width, have been found to be more important than in ordinary reading.

In the chart situation, reading more commonly calls for the recognition of individual letters and numbers than of words and phrases. The secondary conditions are often unfavorable for legibility, especially under cockpit illumination. For such reasons, the results of studies of the reading of continuous text under good light cannot be assumed to apply to charts. A series of preliminary experiments was therefore done to provide some indication of the effect of a number of type characteristics.

In the preliminary experiments, the cross-out task described below was used. The red illumination was set arbitrarily at a level low enough to insure usable scores. All copy was set in monotype Gothic, very similar to the News Gothic used currently for the smaller lettering on aeronautical charts. The typographical variables on which some information was obtained were point size, case, letter-width, stroke-width, and letter spacing. The findings indicated fairly clearly that data on the effect of such variables on the reading of book text under good illumination do not apply to the kind of reading situation we are here concerned with. It is planned to report more fully on this matter later. For the present, we are interested only in the use of these preliminary results as a guide to the selection of type for the main experiment, particularly with respect to letter-width, stroke-width, and letter spacing. Preliminary results favored a medium letter-width and stroke-width, with mean letter spacing in the neighborhood of 50 per cent of mean letter-width.

In the main experiment the only typographical variable was point size, 6- and 8-point being included as the two sizes of most immediate concern. In each of these sizes the copy was set in capitals and lower case (essentially lower case, the first letter only of each line being a capital), with letter-width, stroke-width, and letter spacing near optimum as judged from the preliminary results.

In addition to type size, the experiment covered two aspects of the visual field, illumination level and reflectance of background. The range of illuminations was from 0.014 to 0.129 foot-candles, that of background reflectance from 0.26 to 0.87.

As wave length was not a variable in the experiment, either white or red light might have been used. The choice of red light was dictated, aside from its availability, by two considerations. (1) Its realism for the operational situation with which we are concerned, which might be of some practical consequence in view of the difference in acuity under red and white light at low intensity levels which has been reported (1). (2) The greater convenience of red light in connection with the selection of papers of desired reflectances. Under white light the preference would be for gray paper, but gray papers of the desired characteristics were found to be difficult to obtain. Since a variety of colored papers, which are indistinguishable from gray under red light, was available, it was only necessary to select colors of the necessary red light reflectance.

EXPERIMENTATION

A. Apparatus

1. The Booth and Work Space

The experimental room consisted of a walk-in refrigerator whose heavy walls provided sound insulation and light proofing. An inter-com permitted communication with the experimenter outside the booth, and an exhaust fan served for ventilation.

The subject sat at a small table fixed to the floor. A working surface, which sloped away from the subject at 42° to the vertical, for reasons described below, was mounted on the table top. The ring element from a notebook binder was so positioned as to hold the center of the test material about six inches from the lower edge of this surface. This brought the test material somewhat below eye level, making the line of regard approximately normal to the working surface. A head rest permitted some freedom of movement, but served to maintain a minimum reading distance of 14 inches.

It was necessary for the subject to mark the cross-out test on the sloping surface. No difficulty was experienced with this, but a wrist-pad was provided for the subject's use if desired.

2. The Light Source

The working surface was illuminated from above. The light assembly was contained in a box approximately 18 inches high by seven inches square outside measurements. The source lamp, a Westinghouse spotlight No. 4345, was mounted near the top of the box with the beam directed downward. Below the lamp was a variable angle louver system for fine intensity control. Further down were slots for the insertion of ground glass, opal glass, or photographic plate filters for stepwise intensity control, and at the lower end of the box, slots for a chromatic filter. At this level the beam was restricted to an area 5 1/2 by 5 3/4 inches.

In the current experiment the lamp, which has a rating of 6.4 volts DC, was burned at 4.5 volts. Gross intensity control and some diffusion were provided by two ground glass filters. The chromatic filter was a Corning red, No. 2403.

At the top end of the box was a light-baffled ventilating aperture, and a small fan was kept running inside the box, between the lamp and the vent. The box was light tight except for the beam exit at the bottom and a small amount of light leakage around the ventilator. The leakage was shielded from the subject and the working surface by secondary screening.

As the paper on which the test copy was printed was not perfectly diffusing, and as the incident illumination was limited to a fairly small

solid angle, there was danger of glare produced by specular reflection. Since the surface properties of the several papers were not uniform among themselves, this could operate as an uncontrolled source of variability in the reading performance. The angle of the working surface, and the position of the light box in relation to it, were therefore adjusted to minimize this effect. The light box was suspended from the ceiling and wall, its lower end approximately 18 inches above the center of the working area. The long axis of the box was inclined 10° to the left of the vertical, and the lateral position of the box accordingly adjusted to bring the optical axis in line with the center of the working area. There was also a slight displacement of the box forward relative to the center of the working area, but no inclination in this plane. With this arrangement, all of the papers appeared essentially free from glare as seen from the subject's point of view.

Setting of the louvers for intensity control was accomplished by means of a knob and dial mounted on the side of the light box. As it was necessary for the subject to vary the illumination in the course of the experiment, a supplementary circuit was designed by means of which the experimenter could check the settings. For this purpose a special control scale was constructed on which the settings to be used were indicated in large letters. A series of contact points embedded in the surface of this scale was so wired to a set of coded pilot lights on the experimenter's control panel that when a setting was correctly made the corresponding pilot light went on. A red jewel pilot light operating at very low intensity was turned on briefly between trials inside the booth to enable the subject to see the scale markings.

3. The Control Panel

The experimenter's control panel included, in addition to the bank of pilot lights, switches for the control of the source light, the ventilating system, the inter-com, and the supplementary scale light.

B. The Test Materials

1. The Cross-Out Task

In the cross-out task, the subject was required to read a geographic name, and to cross out, from a group of scrambled letters, all the letters which appeared in the name. All the geographic names were of six letters, and were picked at random from a large atlas. The scramble included the six letters contained in the name, plus 14 others picked at random for a total of 20. Scores on this task from a group of subjects showed clear differences between experimental conditions in both the preliminary experiments and the current experiment.

In discussing results it will be convenient to reserve the term "item" for an individual letter, which was the unit of scoring. A "line" contained six items, and consisted of one name and its associated scramble. In the current experiment, six forms of eight lines each were used. A sample test sheet, as marked by a subject, is shown below.

1	Adrano	kshreiojycapqdvnsmwx
2	Berach	gmtjuirwvhosxefqpkbs
3	Convoy	sytaezgypmorcxflbdgh
4	Malaya	udibamxlnakaqvwhycsr
5	Dwarka	ikwrydgrhoacextnafum
6	Dacula	vquxbjdecpfylasrwaon
7	Gercus	prvalyztduenkmbwgchf
8	Minago	xqjalofhcgwdmkneudtz

Sample Test Sheet

2. The Type.

The type was a monotype Gothic in 6- and 8-point capitals and lower case, in medium letter-width ("regular" as distinguished from "condensed"), medium stroke-width, and with fairly wide letter spacing. The 6-point was printed from the original monotype, the 8-point was a photographic enlargement of the 6-point in the ratio 1.3/1. This ratio was selected to approximate the ratio letter heights in 8- and 6-point in similar type faces. For 6-point, height of the capitals was 1.65 mm, of lower case loops, 1.2 mm. Mean lower case letter width was 0.89 of loop height, stroke width, 0.27 of loop height. Mean letter spacing was 0.48 of mean lower case letter width. For 8-point, of course, all dimensions were increased by 1.3, and the internal ratios remained the same. The sample above is in 6-point.

3. The Paper

After some trial and error, three papers with red light reflectances of 0.87, 0.49, and 0.26 were selected. The lightest of the three was a good quality of white bond. The second was reddish as seen in white light, and the third was light blue. Under red light the hues were not distinguishable. Each form of the test copy in each type size was printed on all three backgrounds.

The specifications for type and paper outlined here apply to the experimental trials proper. In three practice trials for each period, type and paper differed in some details, but were generally similar to those in the regular trials.

4. Spatial Arrangements

The eight lines of 6-point type on a test sheet covered an area approximately 1 3/4 by 2 inches, the 8-point, 2 3/8 by 2 5/8. The copy was centered near the lower edge of a sheet 8 1/2 inches wide by 3 3/4 inches high. The sheets for an experimental period were stacked in order, and mounted, face down, just above the working area by means of the notebook rings. Thus the sheets could be turned down one by one into the working

position, face up. The trial number and illumination setting were marked in large characters on the front and back of each sheet.

C. Illumination and Reflectance Measurements

All light measurements were made with the Macbeth illuminometer directed at the center of the working area from the subject's point of view. Unless otherwise specified, the Macbeth test plate was positioned at the measuring point. It was necessary to calibrate the louvers for intensity control, to determine the level of red illumination over the range with the Corning filter in the system, and to determine the red light reflectances of the papers.

To calibrate the louvers, it was necessary to measure the illumination on the working area as a function of scale setting. This was done by one individual, with the Corning filter removed to permit white light matchings. From these measurements the required curve was drawn.

The next step was to correct these readings for the transmission of the red filter. This transmission value was determined separately by four individuals, each of whom did a white light match with the red filter out of the system and a heterochromatic match with the filter in. Transmission values as determined by the four individuals ranged from 0.033 to 0.044, with a mean of 0.037. The spread here derives mostly from inter- rather than intra-individual variability, as each of the four was sufficiently experienced with heterochromatic photometry to show good consistency from trial to trial. The mean of 0.037 was taken as the best estimate of the red filter transmission in the experimental setup. From this, the red light illumination values for the various louver scale settings were computed.

The values as determined in this way pertained to the center of the working area. Because of the illumination angle there was some non-uniformity over the area. A rough estimate in terms of relative distances indicated that the maximum difference in illumination between the upper and lower edges of the test copy would be in the neighborhood of 10%.

One further source of variation was a small voltage drop at the source lamp in the course of the experiment. Check measurements showed that this could have resulted in a 10% drift in the illumination. The design insured that such a drift would affect all of the experimental combinations about equally. The illumination figures given above are correct for approximately the mean voltage condition.

The final step was measurement of the red light reflectance of papers. For this purpose, with the red filter in position, a match on each of the papers was compared with a match on the test plate. All matches were heterochromatic, and were again done by four individuals. The spread here was much less, the largest being from 0.84 to 0.89 for the white paper. As part of this same operation, reflectance of the printing ink was measured. Mean reflectances for the four samples were white paper, 0.87, red paper, 0.49, blue paper, 0.26, and black ink, 0.049.

D. Subjects

Subjects were 12 male students and staff members 19 to 30 years of age, screened on the Bausch and Lomb Ortho-Rater. All were free from excessive phoria, had normal color vision, and had binocular acuity of 20/20 or better at near and far except for one 20/22.

E. The Variables and Experimental Design

The general plan of the experiment called for obtaining a measure of performance as a function of illumination, for each of the three background reflectances with each of the two type sizes. The six reflectance and type size combinations varied in difficulty, and the illumination ranges within which meaningful scores could be obtained for them correspondingly varied. Six partly overlapping illumination ranges were therefore established, and four values were selected in each, as follows: for background reflectance 0.26 and 6-point type, 0.043, 0.057, 0.075, and 0.129 foot-candles; for reflectance 0.49 and 6-point type, 0.021, 0.037, 0.057, and 0.102 FT-C; for reflectance 0.87 and 6-point type, 0.014, 0.028, 0.043, and 0.070 FT-C; for reflectance 0.26 and 8-point type, 0.021, 0.037, 0.057, and 0.102 FT-C; for reflectance 0.49 and 8-point type, 0.014, 0.028, 0.043, and 0.070 FT-C; for reflectance 0.87 and 8-point type, 0.014, 0.021, 0.028, and 0.051 FT-C.

This gave 24 combinations of variables in the experimental design. Each of the 12 subjects was given each of the 24 combinations once. For the group of 12 subjects, each of the six test forms appeared with each of the experimental combinations the same number of times. All combinations had the same mean serial position. The design was therefore balanced with respect to experimental variables, their combinations, forms, and serial position.

No form followed itself, and no two successive illumination levels differed by more than 0.032 FT-L.

F. Procedure

Each subject had one experimental period of about an hour. Testing was preceded by 10 minutes of dark adaptation. Three practice trials were given before the 24 regular trials, at illuminations selected to sample the range, and to terminate at a value near that of the first regular trial. Each trial had a time limit of one minute. About 15 seconds elapsed between trials, during which the test sheet and illumination setting were changed. A three-minute rest period was allowed after the twelfth regular trial.

At the beginning of the period the subject was given written instructions which explained the task and procedure, and included the admonitions to work for speed and accuracy, to continue trying on the difficult sheets for the full minute, and to call out "time" if he happened to finish an easy sheet before the minute was up. He was then instructed about the writing position, the head rest, the process of changing test sheets, and the illumination control.

The step-by-step procedure for a trial was as follows. The experimenter told the subject where to set the light control. When the setting had been checked the experimenter said "ready", the subject replied "ready" and the

experimenter said "go". At the go signal the subject turned down the test sheet on the top of the stack into the "face up" position, called out the trial number and illumination setting marked on the sheet, and started working. After one minute the experimenter turned out the light momentarily as a stop signal. The subject tore off the sheet he had just finished and laid it aside. The instruction for the next light setting was then given.

G. Results

Each line of the test material contained six items of one letter each, the total for a sheet being 48.

The sheets were scored for letters properly crossed out and for errors. Errors were of two kinds, (1) letters incorrectly crossed out, and (2) omissions. Omissions were counted for the lines in which the subjects marked less than six items, the score for such a line being six minus the number marked. No omissions were counted for the line on which the subject was working when time was called.

Speed and accuracy scores were derived. The measure of speed for a trial was taken to be the total of items right plus errors, and the measure of accuracy, items right as a percentage of the total. "Items right plus errors" is the same as items attempted except for the inclusion in errors of a few omissions which may have been the result of deliberate skipping by the subject. To check on this factor the data were recomputed with omissions eliminated. This changed the results in some details but did not significantly affect the general pattern of the curves. The recomputed figures are therefore not shown.

Mean speed and accuracy scores for the 12 subjects are presented in Table I and Figures 1 and 2.

Figure 1 shows speed in terms of items right plus wrong as a function of illumination for the three background reflectances and two type sizes. Figure 2 shows the corresponding data for accuracy. All curves were fitted by visual inspection. Agreement between speed and accuracy is reasonably good.

Figures 3 and 4, which were derived from Figures 1 and 2, show time and errors as a function of background reflectance for the two type sizes and several illumination levels. The plotted points represent intersections of the curves of Figures 1 and 2 with ordinates erected at the appropriate illumination levels.

H. Discussion

The more specific application of these results to the chart situation will be developed in a subsequent report, in relation to colorimetric aspects of the problem previously analyzed and to other work in progress. The colorimetric work referred to is covered in an unpublished report (2). The present discussion will be limited to some of the more general characteristics of the data.

The expected improvement in performance with increasing illumination, reflectance, and type size shows clearly in the graphs. Though the curves do

TABLE I

MEAN SPEED AND ACCURACY SCORES ON CROSS-OUT TASK (12 SUBJECTS)

SPEED (items right plus errors)

ILLUMINATION (FT-C)	REFLECTANCE .87		REFLECTANCE .49		REFLECTANCE .26	
	8-pt	6-pt	8-pt	6-pt	8-pt	6-pt
.014	22.2	16.5	13.8	——	——	——
.021	23.8	——	——	13.1	9.8	——
.028	24.3	21.6	20.5	——	——	——
.037	——	——	——	16.2	15.8	——
.043	——	21.8	21.5	——	——	10.8
.051	26.1	——	——	——	——	——
.057	——	——	——	19.9	18.7	14.8
.070	——	22.8	24.1	——	——	——
.075	——	——	——	——	——	15.8
.102	——	——	——	21.8	21.6	——
.129	——	——	——	——	——	20.2

ACCURACY (percent items correct)

ILLUMINATION (FT-C)	REFLECTANCE .87		REFLECTANCE .49		REFLECTANCE .26	
	8-pt	6-pt	8-pt	6-pt	8-pt	6-pt
.014	89.30	76.68	72.48	——	——	——
.021	90.82	——	——	70.58	51.64	——
.028	89.40	86.09	83.93	——	——	——
.037	——	——	——	78.41	73.46	——
.043	——	91.08	86.05	——	——	57.94
.051	93.04	——	——	——	——	——
.057	——	——	——	85.30	73.60	63.83
.070	——	89.35	92.36	——	——	——
.075	——	——	——	——	——	73.22
.102	——	——	——	89.16	85.28	——
.129	——	——	——	——	——	81.41

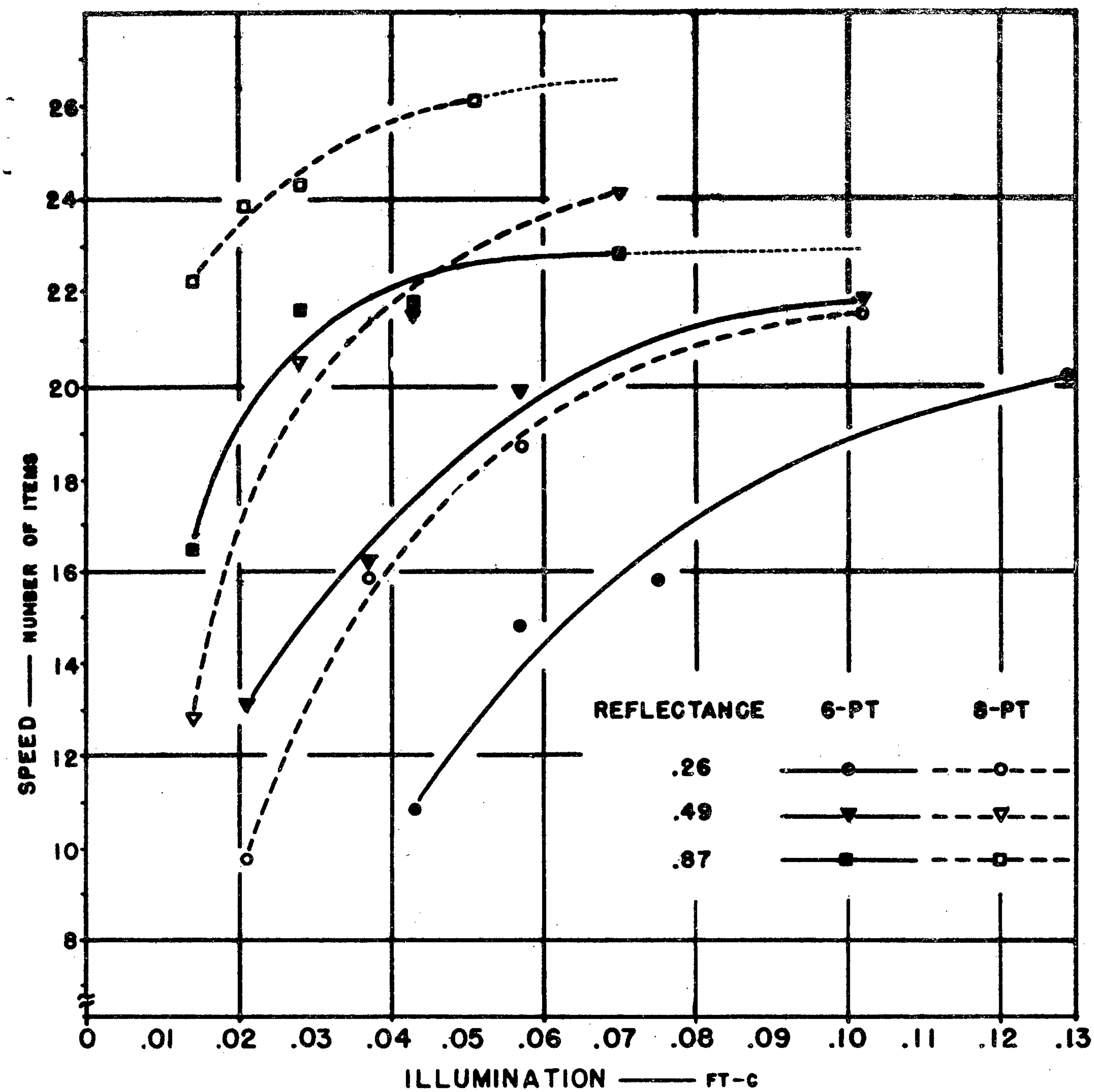

Figure 1. Speed on cross-out task in terms of items right plus errors, as a function of illumination level. Mean scores, 12 subjects. The curves for reflectance 0.87 have been extrapolated to provide additional points for the derived graphs of Figure 3.

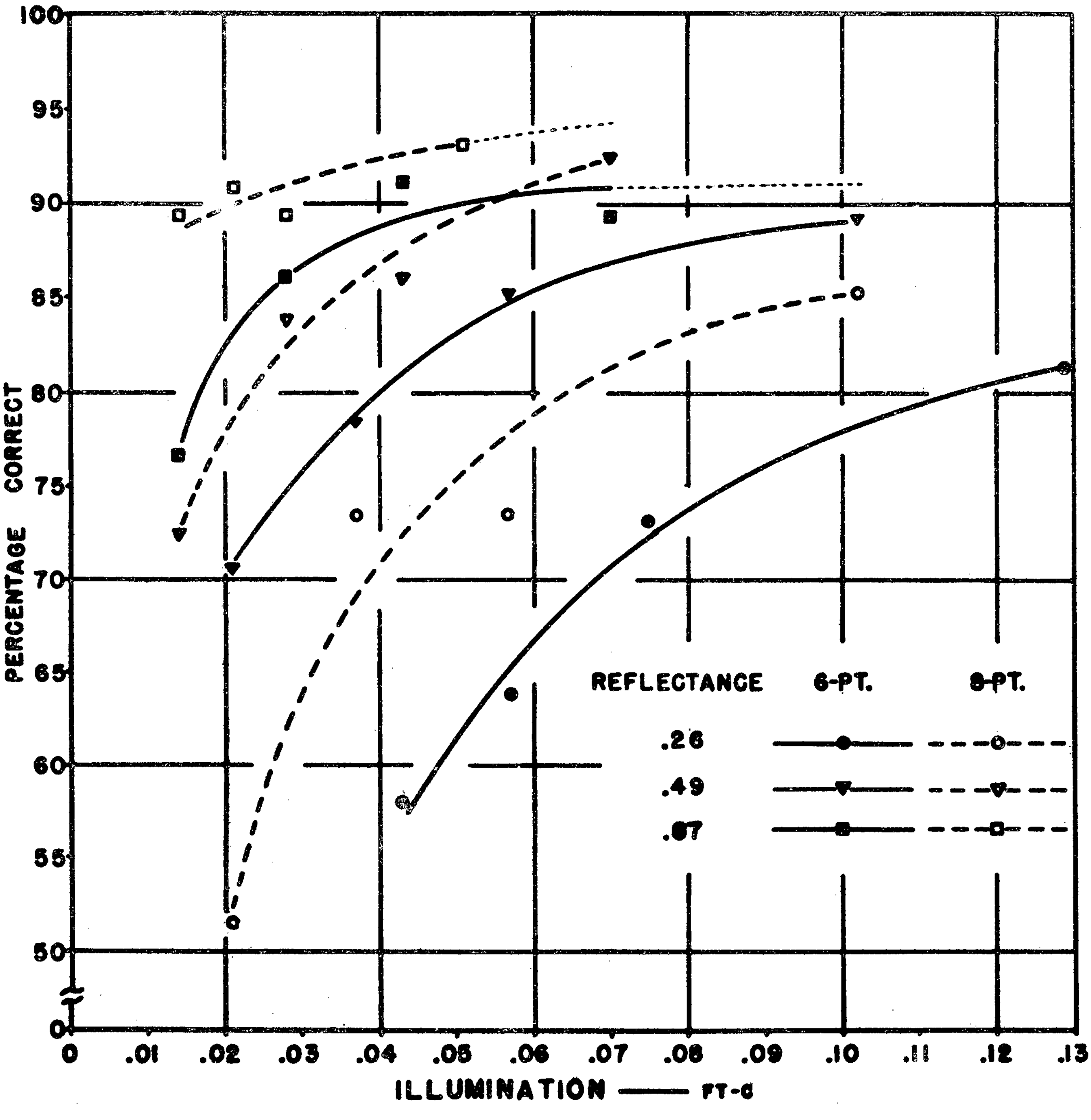

Figure 2. Accuracy on cross-out task in terms of items right as a percentage of items right plus errors, as a function of illumination level. Mean scores, 12 subjects. The curves for reflectance 0.87 have been extrapolated to provide additional points for the derived graphs of Figure 4.

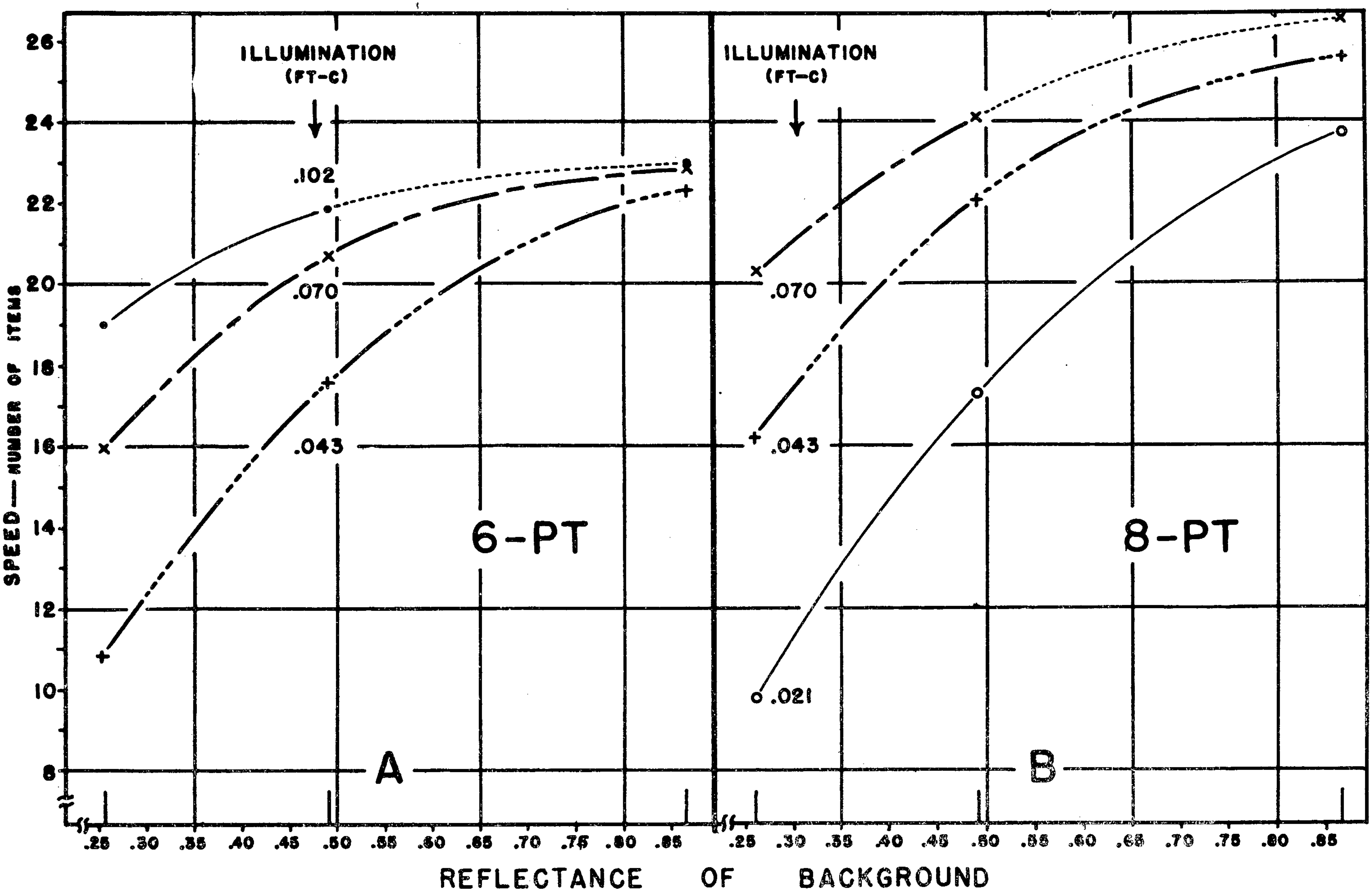

Figure 3. Speed on cross-out task in terms of items right plus errors, as a function of reflectance of background. Mean performance, 12 subjects. Derived from curves of Figure 1. The points for reflectance 0.87, highest illumination in each type size, are based on extrapolated segments of Figure 1 curves.

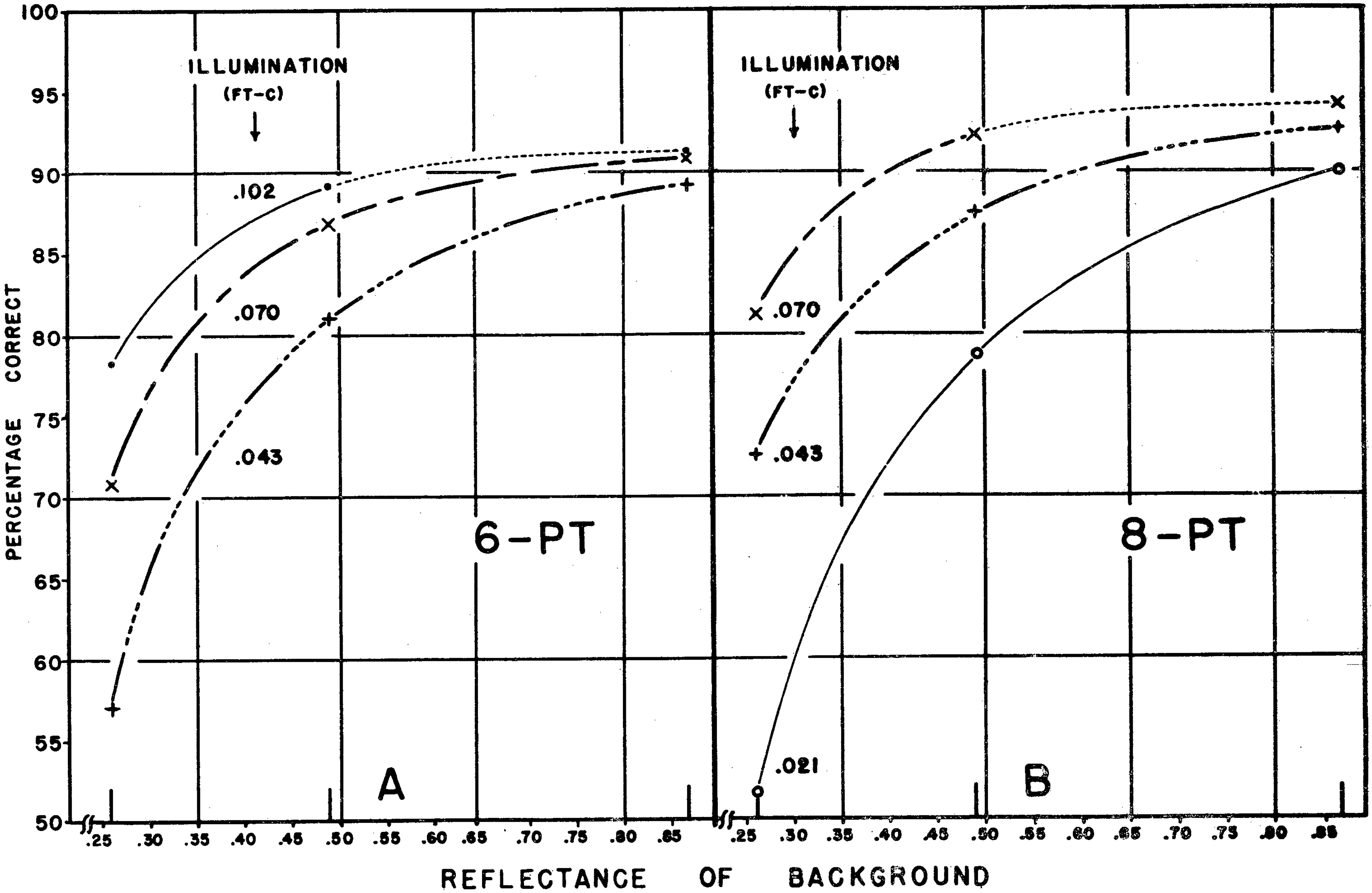

Figure 4. Accuracy on cross-out task in terms of items right as a percentage of items right plus errors, as a function of reflectance of background. Mean performance, 12 subjects. Derived from curves of Figure 1. The points for reflectance 0.87, highest illumination for each type size, are based on extrapolated segments of Figure 1 curves.

not go far enough to establish the final levels with certainty, it appears that the maximum accuracy attainable at high illuminations would be something less than 100%, even for 8-point type. The final level can be expected to vary with the nature of the task as well as with the visual conditions. Our main interest lies in the rate at which performance drops off as a function of decreasing values of the experimental variables.

It is apparent that performance is impaired not only by decrements in the variables considered separately, but in increasing amounts when they occur in combination. For example, if we assume certain more or less arbitrary maximum scores on the basis of the final levels the curves appear to be approaching, and combine speed and accuracy in a rough computation, reducing reflectance of background from near maximum to 0.50 at an illumination level of 0.070 FT-C causes perhaps a six or seven per cent drop in performance with not much difference between 6- and 8-point type; a reduction of background reflectance to 0.35, which is near the lower limit of elevation tint reflectance on current aeronautical charts, causes a drop in performance with 8-point type of approximately 12%, and with 6-point type, 16%. The exact figures arrived at in this illustration are of little significance because of the arbitrary assumptions and method of treatment, but they probably give a fairly correct picture of the relative magnitudes of the effects. At lower illumination levels the legibility loss with decreasing reflectance is more rapid.

It may be a matter of some curiosity why the estimated impairments above are not larger, in view of the wide range of background reflectances. A partial explanation lies in the fact that the range of contrasts is fairly small. If we take 0.049 as the reflectance of the printing ink, and apply the formula $DI/(I + DI)$, in which I is the lesser of the two brightnesses, the contrast values corresponding to the three experimental background reflectances are as follows: for reflectance 0.26, contrast 0.81; reflectance 0.49, contrast 0.90; and reflectance 0.87, contrast 0.94. Black ink provides near the maximum contrast for overprinting darker than the ground. Colored inks generally, with the exception of dense blue, have much higher red light reflectances, and the contrast between such inks and colored backgrounds is sometimes so low that reading is impossible.

The application of the data reported here to operational situations is subject to additional qualifications and precautions. It will be recalled that the type used for the experiment was selected, in respect to some of its more important characteristics, for maximum legibility under low illumination. It is probable that any type less suitable in these characteristics would show even greater and more rapidly accelerated impairment of reading performance. It is also necessary to recognize that overprinting on charts is often subject to special conditions which hamper legibility, as crowding from adjacent material, and sometimes actual superposition of various kinds of secondary lines. It is therefore advisable to consider the degree of impairment from the experimental variables reported here as near the minimum that would be operationally encountered.

I. Conclusions

The legibility of 6- and 8-point Gothic lower case black print falls off at an accelerated rate as, (1) the level of red illumination is reduced from 0.129 to 0.014 FT-L, and (2) reflectance of background is reduced from 0.87 to 0.26. The legibility is less in all cases for 6-point than for 8-point type.

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The legibility of lower-case type as a function of illumination level, reflectance of background, and type size was measured by means of speed and accuracy scores on a letter cross-out test. Simulated red cockpit illumination was used, covering the range (over)

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